APPLICATION

FOR

UNITED STATES LETTERS PATENT

TITLE: FLUORINATED π-BRIDGE SECOND ORDER NONLINEAR OPTICAL CHROMOPHORES AND ELECTRO-OPTIC DEVICES THEREFROM

APPLICANT: DIYUN HUANG

CERTIFICATE OF MAILING BY EXPRESS MAIL

Express Mail Label No. EV414278444US

January 14, 2004

Date of Deposit

Fluorinated π-Bridge Second Order Nonlinear Optical Chromophores and Electro-optic Devices Therefrom.

All patents, patent applications, and publications cited within this application are incorporated herein by reference to the same extent as if each individual patent, patent

5   application or publication was specifically and individually incorporated by reference.

RELATED APPLICATIONS

This application is a continuation-in-part of Patent Application No. 10/301,978 filed November 22, 2002, entitled "Second Order Nonlinear Optical Chromophores and Electro-

10   optic Devices Therefrom," which is a continuation-in-part of Patent Application No. 09/932,831 filed August 17, 2001, entitled "Design and Synthesis of Advanced NLO Materials for Electro-Optic Applications," which is assigned to the same assignee as the present application, which claims benefit of Provisional Application No. 60/226,267 filed August 17, 2000, and which is hereby incorporated by reference in its entirety.

15   ## BACKGROUND OF THE INVENTION

The invention relates generally to the organic chromophores for second order nonlinear optical (NLO) applications, compositions including such chromophores, and applications including such chromophores and compositions.

The development and uses of NLO chromophores, including polymer matrix

20   development, waveguide fabrication, and optical device fabrication are well documented. An NLO chromophore (also known as a "push-pull" chromophore) comprises three fundamental building blocks represented by the general formula D-π-A, where D is a donor, π is a π-bridge, and A is an acceptor. In the art, a "π-bridge" is sometimes referred to as a "π-conjugated bridge," "π-electron bridge," "conjugated π-electron bridge," and the like. Examples of such bridges are

25   described, for example, in U.S. Pat. No. 5,670,091, 5,679,763, 6,067,186, and 6,090,332. A "π-bridge" allows charge transfer from a donor to an acceptor in a chromophore. Exemplary acceptors are shown in Fig. 1, where, independently at each occurrence, R^1 is hydrogen, a halogen except when bonded to a carbon alpha to or directly to a nitrogen, oxygen, or sulfur atom, or an alkyl, aryl, heteroalkyl, or heteroaryl group; Y is O, S or Se; and q is 0 or 1.

Exemplary donors are shown in Fig. 2, where, independently at each occurrence, R^1 is hydrogen, a halogen except when bonded to a carbon alpha to or directly to a nitrogen, oxygen, or sulfur atom, or an alkyl, aryl, heteroalkyl, or heteroaryl group; R^2 is hydrogen or an alkyl, aryl, heteroalkyl, or heteroaryl group; Y is O, S or Se; m is 2, 3 or 4; p is 0, 1 or 2; and q is 0 or 1.
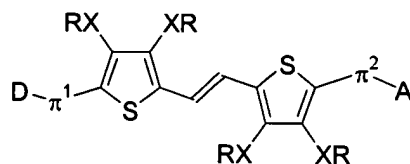
5   Herein, a heteroalkyl group includes, but is not limited to, functional groups, halogen substituted alkyl groups, perhalogenated alkyl groups, and dendrons. What is meant by a functional group in generally understood in the art of organic chemistry, for example see Appendix B in Jerry March, "Advanced Organic Chemistry" 4th Edition, John Wiley and Sons, New York, pp 1269-1300. A "dendron" is a substituent that has regularly repeating subunits. A dendron may be

10   further comprised of one or more heteroaryl group. A "dendrimer" is a macromolecular structure that contains a "core" surrounded by one or more dendrons. Often in the art, the terms dendron and dendrimer are used interchangeably. Dendrons and dendrimers are illustrated and discussed in Bosman et al., *Chem. Rev.* 1999, 99, 1665 and U.S. Pat. No. 5,041,516.

The particular D-π-A arrangement affects the ability of the molecule to achieve

15   large second order NLO effects. Thus, the first molecular electronic hyperpolarizability (β, sometimes given as µβ, where µ is the dipole moment of the chromophore), which is a measure of this ability, can be tuned and optimized by changing the electronic properties of any one of D, π, or A, *see* Gorman and Marder *Proc. Natl. Acad. Sci, USA* 1993, 90, 11297. Molecular NLO effects, in turn, can be translated into bulk EO activity in a material by aligning molecules in one

20   direction by applying an electric field.

SUMMARY OF THE INVENTION

In one aspect, a nonlinear optical chromophore has the formula D-π-A where π is a π bridge including a thiophene ring having oxygen atoms bonded directly to the 3 and 4 positions of the thiophene ring, D is a donor, and A is an acceptor. The oxygens bonded directly

25   to the 3 and 4 ring positions of the of the thiophene ring may be further independently substituted with an alkyl group comprising 1 to about 20 carbons, a heteroalkyl group comprising 1 to about 20 carbons, an aryl group comprising 1 to about 20 carbons, or a heteroaryl group comprising 1 to about 20 carbons.

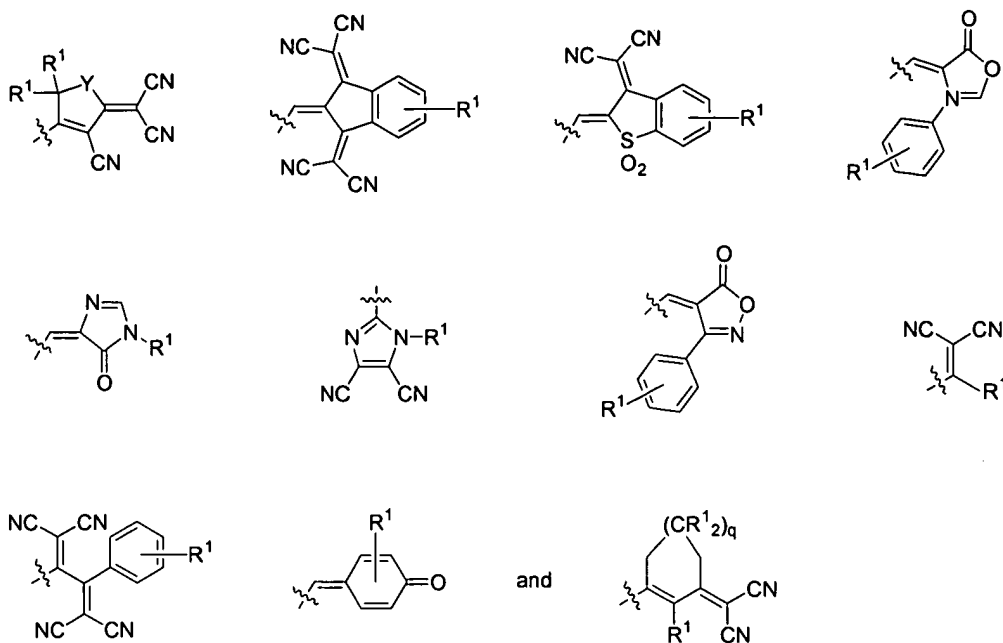In a second aspect, a nonlinear optical chromophore has the formula:

5   wherein, independently at each occurrence: π^1 is absent or a π-bridge; π^2 is absent

or a π-bridge; D is an donor; A is an acceptor; X is O or S; and R is an alkyl group comprising 1

to about 20 carbons, a heteroalkyl group comprising 1 to about 20 carbons, an aryl group

comprising 1 to about 20 carbons, or a heteroaryl group comprising 1 to about 20 carbons.

These chromophores may be combined with a polymer matrix to form second order nonlinear

10   optical compositions useful in a variety of applications, including electro-optic devices such as

optical modulators, optical switches, and optical directional couplers. For example, the

chromophore and polymer matrix may contain crosslinkable functional groups, and may be

combined to form a guest-host composite, in which the chromophore is the guest and the

polymer matrix is the host. An electric field is then applied to the composite to induce electro-

15   optic activity, after or during which the composite is crosslinked to covalently bond the

chromophore to the polymer matrix. Other features and advantages of the invention will be

apparent from the following description of preferred embodiments thereof, and from the claims.

          Another embodiment is a nonlinear optical chromophore having the formula D-π-

A, wherein π is a π bridge including a thiophene ring having oxygen atoms bonded directly to the

20   3 and 4 positions of the thiophene ring, D is a donor, A is an acceptor, and the oxygen atoms are

further substituted with a fluorinated group comprising at least three fluorines. Some examples

of fluorinated groups comprising at least three fluorine atoms are 2,2,2-trifluoroethyl; 2,2,3,3,3-

pentafluoropropyl; 2,2,3,3,4,4,4-heptafluorobutyl; 2,2,3,3,4,4,5,5,5-octafluoropentyl; 3,3,4,4,-

5,5,6,6,7,7,8,8,8-tridecafluoro-1-octyl; 2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-pentadecafluorooctyl; 1-

25   trifluoromethyl-2,2,2-trifluoroethyl; 1-trifluoromethyl-2,2,3,3,3-pentafluoropropyl; 2,3,4,5,6-

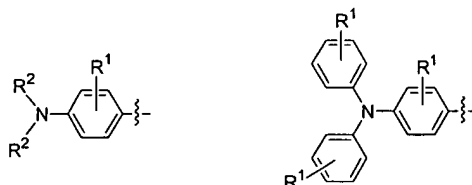pentafluorobenzyl; and (2,3,4,5,6-pentafluorophenyl)ethyl.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 illustrates exemplary acceptors that can be used in some embodiments.

Fig. 2 illustrates exemplary donors that can be used in some embodiments.

Figs. 3-6 outline syntheses of various nonlinear optical chromophores.

5   Fig. 7 outlines a synthesis of a crosslinkable polymer used in some embodiments.

Figs. 8-10 outlines a synthesis of various π-bridge fluorinated chromophores.

DETAILED DESCRIPTION

The second order nonlinear optical chromophores have the chemical structures and formulas described above in the Summary of the Invention. Examples of donors (D) that

10   may be used include structures chosen from the group consisting of

Examples of acceptors (A) that may be used include structures selected from the group consisting of
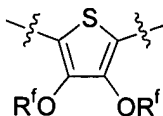
15

wherein independently at each occurrence: R^1 is hydrogen, a halogen except when bonded to a carbon alpha to or directly to a nitrogen, oxygen, or sulfur atom, or an alkyl, aryl, heteroalkyl, or

5   heteroaryl group; R^2 is hydrogen or an alkyl, aryl, heteroalkyl, or heteroaryl group; Y is O, S or Se; m is 2, 3 or 4; p is 0, 1 or 2; and q is 0 or 1. Preferably, the donor is chosen from the group consisting of

10   wherein independently at each occurrence: R^1 is hydrogen, a halogen except when bonded to a carbon alpha to or directly to a nitrogen, oxygen, or sulfur atom, or an alkyl, aryl, heteroalkyl, or heteroaryl group; and R^2 is hydrogen or an alkyl, aryl, heteroalkyl, or heteroaryl group.
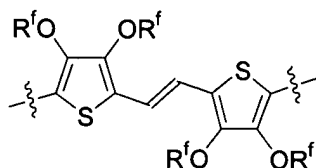
Another embodiment is a nonlinear optical chromophore having the formula D-π-

A, wherein π is a π bridge including a thiophene ring having oxygen atoms bonded directly to the

15   3 and 4 positions of the thiophene ring, D is a donor, A is an acceptor, and the oxygen atoms are further substituted with a fluorinated group comprising at least three fluorines. The fluorinated groups provide increased compatibility between the chromophore and fluorinated polymer hosts.

5

Preferably, the π-bridge comprises:

wherein independently at each occurrence R^f is a fluorinated group comprising at least three fluorines. Another example of a π-bridge is

5

wherein independently at each occurrence R^f is a fluorinated group comprising at least three fluorine atoms. The π-bridges may be prepared by reacting, for example, as shown in Figure 8,

10   compound **18** with an electrophilic reagent such as a triflate. Other electrophilic fluorinating reagents may also be used, for example see Umemoto, T. *Chem. Rev.* **1996**, *96*, 1757-1777. The chromophores including the π-bridges may be prepared by techniques, for example, as outlined in Figures 8-10. The donors and acceptors are as described above. Preferably, the fluorinated group has the formula $-(CH_2)_t(CF_2)_vF$ or $-(CH_2)_t(CF_2)_wH$, where t = 1 to 5, v = 1 to 20, and W =

15   2 to 20. Some examples of fluorinated groups comprising at least three fluorine atoms are 2,2,2-trifluoroethyl; 2,2,3,3,3-pentafluoropropyl; 2,2,3,3,4,4,4-heptafluorobutyl; 2,2,3,3,4,4,5,5,5-octafluoropentyl; 3,3,4,4,-5,5,6,6,7,7,8,8,8-tridecafluoro-1-octyl; 2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-pentadecafluorooctyl; 1-trifluoromethyl-2,2,2-trifluoroethyl; 1-trifluoromethyl-2,2,3,3,3-pentafluoropropyl; 2,3,4,5,6-pentafluorobenzyl; and (2,3,4,5,6-pentafluorophenyl)ethyl.

20   The chromophores may be combined with a polymer matrix to form compositions useful in a variety of electro-optical applications. Such compositions may be prepared according to a number of known techniques, including those described in US Pat. No. 5,776,374; 5,714,304; 5,223,356; 5,433,895; 6,294,573; 6,126,867; 5,811,507; 5,635,576; 5,520,968; 5,359,008; 5,266,365; 5,207,952; and 6,228,977 and *Chem. Mater.* 2000, *12*, 1187; *J. Am Chem.*

25   *Soc.* 2001, *123*, 986; *Macromolecules* 1992, *25*, 4032; *Chem. Mater.* 1999, *11*, 2218; and *Chem.*

Mater. 1998, *10*, 146. In one embodiment, the chromophore is a guest in the crosslinked polymer matrix host. In another embodiment, the chromophore is covalently incorporated into a crosslinked polymer matrix, the chromophore being at first a guest in a crosslinkable polymer matrix host. Preferably, the polymer matrix is fluorinated. The backbone of the polymer matrix

5   can be fluorinated or pendant groups of the polymer matrix can be fluorinated (for example, 17 in Figure 7).

Another embodiment is a process comprising: 1) providing a guest chromophore in a polymer host, wherein both the guest chromophore and polymer host contain fluorinated crosslinkable groups; 2) applying an electric field to the composite to induce electro-optic

10   activity; and 3) crosslinking the composite, whereby the chromophore guest is covalently incorporated into the polymer host to provide a crosslinked nonlinear optical material. This method has advantages over other conventional processes, such as: 1) the chromophore guest and polymer host are compatible due to both having fluorinated crosslinkable groups; 2) the nonlinear optical material produced will have lower loss at 1550 nm since the crosslinking

15   groups are fluorinated; 3) the chromophore host has more degrees of freedom to align with the poling field since it is not covalently incorporated into the polymer host before the poling filed is applied; and 4) the molecular weight and composition of the polymer are precisely known, which will allow control of critical parameters like film thickness, T_g, and solubility.

The nonlinear optical compositions may be used to fabricate optical devices,

20   optical switches, modulators, waveguides, or other electro-optical devices that can be used in communication systems using methods known in the art. For example, in optical communication systems, devices fabricated including compositions described above may be incorporated into routers for optical communication systems, waveguides for optical communication systems, or for optical switching or computing applications. Because polymers are generally less demanding

25   than currently used materials, devices including compositions described above may be more highly integrated.

Specific examples of components of optical communication systems that may be fabricated in whole or in part from the nonlinear optical compositions described above include, without limitation, straight waveguides, bends, single-mode splitters, couplers (including

30   directional couplers, MMI couplers, star couplers), routers, filters (including wavelength filters),

switches, modulators (optical and electro-optical, *e.g.*, birefringent modulator, the Mach-Zender interferometer, and directional and evanescent coupler), arrays (including long, high-density waveguide arrays), optical interconnects, optochips, single-mode DWDM components, and gratings.

5   Waveguides made with nonlinear optical compositions described above may be used in telecommunication, data communication, signal processing, information processing, and radar system devices and thus may be used in communication methods relying, at least in part, on the optical transmission of information. Specific applications in which the above-described nonlinear optical compositions can be incorporated include:

10   (1) an electro-optic device that is an interferometric optical modulator or switch, comprising: 1) an input waveguide; 2) an output waveguide; 3) a first leg having a first end and a second end, the first leg being coupled to the input waveguide at the first end and to the output waveguide at the second end; and 4) and a second leg having a first end and a second end, the second leg being coupled to the input waveguide at the first end and to the output waveguide at

15   the second end, wherein at least one waveguide includes a nonlinear optical composition described above.

(2) an optical modulator or switch, comprising: 1) an input; 2) an output; 3) a first waveguide extending between the input and output; and 4) a second waveguide aligned to the first waveguide and positioned for evanescent coupling to the first waveguide; wherein at

20   least one waveguide includes a nonlinear optical composition described above.

(3) an optical router that includes at least one optical modulator, optical switch, or optical directional coupler comprising a nonlinear optical composition described above.

Additional applications include a communications system including at least one electro-optic device comprising a nonlinear optical composition described above, a method of

25   data transmission including transmitting light through a nonlinear optical composition described above, a method of telecommunication including transmitting light through a nonlinear optical composition described above, a method of transmitting light including directing light through or via a nonlinear optical composition described above, and a method of routing light through an optical system comprising transmitting light through or via a nonlinear optical composition

30   described above.

Additionally, the nonlinear optical compositions described herein may be applied to devices or methods that control the phase of light waves passing through the material. In some applications, electrical fields are applied across a set of waveguides through which the light waves travel. Controlling the electrical fields allows the relative phases of the light waves to be

5   controlled. Such approaches are particularly useful in applications known in the art such as phased-array radar or phase matching of light waves passing through alternative waveguides, for example see, U.S. Pat. No. 5,353,033; 5,051,754; 4,258,386; and 4,028,702. Thus, another embodiment is a phased-array radar comprising a nonlinear optical composition embodiment described above.

10   The following examples are illustrative and are not intended as a limitation thereof.

Examples

Example 1

Referring to Fig. 3, Compound 1, which was prepared as in *Syn. Comm.* **1996**, *26*,

15   2213, (187.8 g, 0.824 mol), dry DMF (127.4 mL, 1.647 mol) and dry dichloromethane (2000 mL) were mixed in a 3-neck flask and cooled to 0 °C. $POCl_3$ (201.6 g, 1.318 mol) was added. The mixture was heated to reflux for 3 h. Then it was poured into 1 M NaOAc solution. It was extracted with CH_2Cl_2, washed with water and dried over $MgSO_4$. After removing the solvent, it was purified by flash column with ethyl acetate/hexane (1:2.5) to give 200 g (95%) of

20   Compound 2.

Zinc (61.5 g, 0.941 mol) and dry THF (950 mL) were placed in a 3-neck flask and cooled to 0 °C. $TiCl_4$ (51.5 mL, 0.469 mol) was added slowly. The mixture was then heated to reflux for half hour. It was then cooled to 0 °C. A solution of compound 2 (60 g, 0.234 mol) and pyridine (49.5 mL, 0.605 mol) in THF (200 mL) was added slowly. The mixture was heated to

25   reflux for 2 h. After cooling to room temperature, ice and CH_2Cl_2 were added. The resulting mixture was filtered through zelite, washed with HCl solution, water and dried over $MgSO_4$. After removing the solvent, the crude solid was purified by recrystallization from methanol to give 42.4 g (75%) of Compound 3.

Compound 3 (75 g, 0.156 mol) and ether (1400 mL) were placed in a flask and cooled to 0 °C. BuLi (2.5 M) (156 mL, 0.39 mol) was added slowly and stirred for 15 min. DMF (57 mL, 0.733 mol) was then added, after which the mixture was warmed to room temperautre and stirred. NH_4Cl solution was added and the solvent was partially removed under reduced

5   pressure. It was then extracted with CH_2Cl_2, washed with water, and dried over $MgSO_4$. After removing the solvent, the crude product was purified by recrystallization from methanol to give 76 g (91 %) of Compound 4.

Compound 5 (2.74 g, 5.44 mmol) and THF (200 mL) were mixed and stirred. At −40 °C, BuLi (2.5 M) (2.4 mL, 5.98 mmol) was added and then stirred at room temperature for

10   30 min. The resulting solution was added slowly to a solution of Compound 4 (2.65 g, 4.94 mmol) in 100 mL THF with stirring. The solution was stirred at room temperature for 8 h, after which the solvent was removed at reduced pressure. The remaining crude material was purified by column chromatography with hexane/CH_2Cl_2/ethyl acetate mixture to give 2.65 g (76 %) of Compound 6 (which may have a slight impurity of di-reacted product).

15   Compound 6 (2.65 g, 3.9 mmol), Compound 7 (1.55 g, 7.8 mmol), $CHCl_3$ (2 mL), and piperidine (2 drops) were mixed and refluxed for 3 h. The reaction was monitored with thin layer chromatography until the bulk color changed to dark blue/green. The product was purified by flash column and regular column chromatography with CH_2Cl_2/ethyl acetate/hexane mixture to give 1.5 g (45 %) of Compound 8.

20   An electro-optic polymer thin film including chromophore Compound 8 was prepared by: 1) obtaining a solution of Compound 8 and poly [biphenyl A carbonate-co-4,4'-(3,3,5-trimethylcyclohexylidene)-diphenol carbonate] from Aldrich (27% by weight loading of Compound 8 with respect to the polycarbonate) in dibromomethane (6.67% by weight loading of the dibromomethane with respect to Compound 8 and the polycarbonate); 2) spin depositing the

25   solution at 500 rpm for 5 sec and 1500 rpm for 30 sec on a 2" diameter indium tin oxide (ITO) substrate; 3) sputtering a gold electrode on the polymer thin film; and 4) poling at 124 °C for 5-10 min in silicon oil with a poling voltage of 100-150 V/μm.

Example 2

Referring to Figs. 4-6, Compound 9 (82 g, 0.107 mol) and THF (2500 mL) were mixed and stirred. At-40 °C, BuLi (2.5 M) (47.4 mL, 0.118 mol) was added and then stirred at room temperature for 30 min. The resulting solution was added slowly to a solution of

5   Compound 4 (50 g, 0.093 mol) dissolved in 1500 mL THF. The resulting solution was then stirred at room temperature for 8 h. The solvent was removed at reduced pressure. The remaining crude material was purified by column chromatography with hexane/CH_2Cl_2/ethyl acetate mixture to give 61.3 g (70 %) of Compound 10.

Compound 10 (61 g, 0.065 mol), Compound 7 (26 g, 0.129 mol), $CHCl_3$ (20 mL)

10   and piperidine (10 drops) were mixed and refluxed for 3 h. The reaction was monitored with thin layer chromatography until the bulk color changed to dark blue/green. The product was purified by flash column and regular column chromatography with CH_2Cl_2/ethyl acetate/hexane mixture to give 36 g (49 %) of Compound 11.

Compound 11 was dissolved in 750 mL THF. HCl solution (1 N, 250 mL) was

15   added and the resulting solution was stirred for 8 h. After checking the reaction with thin layer chromatography, $NaHCO_3$ solution was added. The resulting solution was then extracted with CH_2Cl_2, washed with water, and dried over $MgSO_4$. After removing the solvent under reduced pressure, the remaining material was purified by flash column chromatography with CH_2Cl_2/ethyl acetate mixture to give 17.8 g (63 %) of Compound 12.

20   Compound 13, which can be prepared as in U.S. Pat. No. 5,198,513 or by carbonylation of the lithium salt of Compound 15 (Fig. 7) followed by reaction with thionyl chloride, (23.5 g, 0.099 mol) was dissolved in 50 mL CH_2Cl_2 and cooled to 0 °C. Compound 12 (17.8 g, 0.0199 mol) and pyridine (9.6 mL, 0.119 mol) were dissolved in 200 mL CH_2Cl_2 and added slowly to the solution of Compound 13. The resulting solution was stirred at room

25   temperature for 8 h. The mixture was then extracted with CH_2Cl_2, washed with water, and dried over $MgSO_4$. After removing the solvent under reduced pressure, the remaining material was purified by flash column chromatography with CH_2Cl_2/ethyl acetate mixture to give 21 g (83 %) of Compound 14.

Referring to Fig. 7, a three-neck 500ml flask equipped with a thermometer, a

30   magnetic stirrer bar, and an addition funnel was charged with 25.3 g (0.1mol) of Compound 15,

11

which can be prepared as in *Macromolecules* **1996**, *29(3)*, 852-860). The flask was purged with nitrogen before introducing 200 mL of dry ether and then was cooled in dry ice-acetone bath. 76 mL of 1.7 M *t*-BuLi in pentane was dropped into flask from addition funnel below –65°C. After completion of this addition, the reaction was kept in the above bath for 1 hour. 19.4 g of

5   2,3,4,5,6-pentafluorostyrene was then added and allowed to react for 1h before removing the cooling bath and letting the temperature reach 0°C. At this moment, dilute HCl aqueous solution was poured into the flask to quench the reaction until the aqueous layer became acidic. The organic layer was separated, dried over MgSO$_4$, evaporated, and purified on a silica gel column with hexanes to give Compound 16 as a white solid (10.08 g, 29%).

10   A mixture of Compound 16, (1.7411 g, 5.0 mmol), THF (5 mL), and 2,2'-azoisobutyronitrile (AIBN) in a 25 mL flask equipped with a condenser was kept under nitrogen atmosphere at 76 °C for 5 hours and 60 °C overnight. The reaction was allowed to cool and the polymer was collected after precipitation by the addition of hexanes and filtration to give 1.2 g of Polymer 17 as a white powder.

15   A crosslinked electro-optic polymer thin film including Compound 14 in Polymer 17 was prepared by: 1) preparing a solution of Compound 14 and Polymer 17 (15% by weight loading of Compound 14 with respect to Polymer 17) in cyclopentanone (30% by weight loading of cyclopentanone with respect to Compound 14 and Polymer 17); 2) spin depositing the solution at 500 rpm for 5 sec and 1300 rpm for 30 sec on a 2" ITO substrate; 3) corona poling the system

20   at 180 °C and 4.5 kV for 10 min, 5.5 kV for 5 min, 6.5 kV for 5 min, and 7.5 kV for 5 min; and 4) allowing the crosslinked film to cool to room temperature under the 7.5 kV field.

Example 3

Referring to Figure 8, Compound 19: 2,2,3,3,4,4,4-Heptafluorobutanol (50g,

25   0.249 mol), pyridine (40 mL, 0.499 mol) and methylene chloride (450 mL) were placed in a flask and cooled to 0 °C. Triflic anhydride (63 mL, 0.374 mol) was added with stirring over 30 min. The mixture was stirred at room temperature for 12 h. It was then washed with dilute H$_2$SO$_4$ solution and water, and dried over MgSO$_4$. After filtration, the solvent was removed under reduced pressure. The liquid was purified by vacuum distillation with a boiling point of 47-48 °C

30   at about 20 mmHg. The triflate, 27.8 g, was obtained in 34 % yield and used in the next step.

To a round bottom flask was added NaH (2.27 g, 0.09 mol) and HMPA (35 mL). To this mixture, Compound 18 (9.3 g, 0.035 mol) was added dropwise at room temperature in 120 mL HMPA. After stirring for 0.5 hour, a solution of the triflate prepared above (27 g, 0.081 mol) in 30 mL HMPA was added dropwise at room temperature. The mixture was stirred vigorously and

5   heated at 110 °C for 10 h. It was then poured into ice water, extracted with methylene chloride, washed with water and dried over $MgSO_4$. After filtration, the solvent was removed under reduced pressure. It was purified by column chromatography with 1:3 ethyl acetate/hexane to give 16 g (72 %) of Compound 19.

Compound 20: Compound 19 (15.7 g, 0.025 mol), KOH (7g, 0.126 mol) and

10   EtOH (120 mL) were placed in a flask and heated to reflux for 3 h. The mixture was then poured into 1000 mL water and precipitated by the addition of 3 N HCl. The solid was collected by filtration to give 13.8 g (97 %) of Compound 20.

Compound 21: Compound 20 (11.7 g, 0.021 mol) and Cu_2O (0.4 g) were placed in a flask and mixed. The reaction was heated to 235 °C for 1.5 h. After cooling down, the

15   product was purified by vacuum distillation with (b.p. of 73-74 °C at 0.6 mmHg) to give 7.66 g (77 %) of Compound 21.

Compound 22: Compound 21 (8.7 g, 0.018 mol), DMF (7 mL, 0.09 mol) and 70 mL dichloroethane were added to a flask, and the flask was submerged in an ice bath. At 0 °C, $POCl_3$ (7.6 mL, 0.08 mol) was added. It was heated to reflux for 24 h. The mixture was then

20   poured into 1 N NaOAc solution and extracted with methylene chloride. It was purified by a column chromatography with ethyl acetate/hexane (1:3) to give 5.7 g (62 %) of Compound 22.

Referring to Figure 9, Compound 23: Compound 5 (7.1 g, 0.014 mol) and 150 mL THF were mixed. At –40 °C, BuLi (2.5 M, 6.2 mL, 0.015 mol) was added dropwise and it was stirred at room temperature for 30 min. A solution of compound 22 (5.5 g, 0.011 mol) in 30 mL

25   THF was then added and it was stirred at room temperature for 8 h. After removing the solvent, the mixture was purified by column chromatography with ethyl acetate/hexane (1: 3.5) to give 6.45 g (91 %) of Compound 23.

Compound 24: Compound 23 (6.45 g, 0.01 mol), DMF (6.1 mL, 0.08 mol) and 45 mL dichloromethane were mixed. At 0 °C, $POCl_3$ (5.88 mL, 0.063 mol) was added. The

30   reaction was heated to reflux for 16 h and then poured into NaOAc solution. After extraction

with methylene chloride, the product was purified by column chromatography with ethyl acetate/hexane (1: 2.5) to give 2.65 g (39 %) of Compound 24.

Compound 26: Compound 24 (0.61 g, 0.89 mmol), compound 25, which can be prepared as described in co-pending, commonly assigned US Pat. Appl. No. 09/932,831 (0.385
5   g, 1.79 mmol), chloroform (1 mL) and 1 drop of piperidine were mixed and refluxed for 6 h. The mixture was purified by column chromatography with hexane/ethyl acetate/methylene chloride to give 0.15 g (19 %) of compound 26.

Example 4
10   Compound 27: Zinc (2.57 g, 0.0394 mol) and 40 mL THF were mixed and cooled to 0 °C. TiCl$_4$ (2.2 mL, 0.02 mol) was added and it was refluxed for 30 min. After cooling to 0 °C, a solution of compound 22 (5 g, 0.0098 mol) and pyridine (2.1 mL, 0.0256 mol) in 10 mL THF was added. The reaction was then refluxed for another 2 h, poured into ice water, and extracted with methylene chloride. The mixture was purified by recrystallization from methanol
15   to give 3.13 g (65%) of Compound 27.

Compound 28: Compound 27 (3 g, 0.05 mmol), DMF (0.35 mL, 4.57 mmol) and 40 mL dichloroethane were mixed. At 0 °C, POCl$_3$ (0.37 mL, 3.96 mmol) was added. The reaction mixture was heated to reflux for 16 h and then poured into NaOAc solution. After extraction with methylene chloride, the product was purified by column chromatography with
20   methylene chloride/hexane (1:1) to give 2.03 g (66 %) of Compound 28.

Compound 29: Compound 9 (2.1 g, 2.7 mmol) and 50 mL THF were mixed. At −40 °C, BuLi (2.5 M, 1.2 mL, 3 mmol) was added dropwise and it was stirred at room temperature for 30 min. A solution of compound 28 (2.03 g, 2 mmol) in 30 mL THF was then added and it was stirred at room temperature for 8 h. After removing the solvent, the mixture was
25   purified by column chromatography with ethylene chloride/hexane (1:1) to give 2.02 g (71 %) of Compound 29.

Compound 30: Compound 29 (0.3 g, 0.21 mmol), DMF (0.033 mL, 0.42 mmol) and 10 mL dichloroethane were mixed. At 0 °C, POCl$_3$ (0.033 mL, 0.36 mmol) was added. The reaction mixture was refluxed for 18 h and then poured into NaOAc solution. After extraction

with methylene chloride, it was purified by column chromatography with ethylene chloride/hexane (1:1) to give 0.04 g (15.5 %) of Compound 30.

Compound 31: Compound 30 (0.04 g, 0.033 mmol), compound 7 (0.013 g, 0.066 mmol), chloroform (0.5 mL) and 1 drop of piperidine were mixed and refluxed for 6 h. The mixture was purified by column chromatography with hexane/ethyl acetate/methylene chloride to give 0.012 g (26 %) of Compound 31.

Other embodiments are within the following claims.